# ERS Staff Paper

Economic
Research
Service

Market
and Trade
Economics
Division

Number 9903

# Documentation and Use of DYNAGEM

## A Dynamic Applied General Equilibrium Model for Policy Analysis



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Agriculture

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**Documentation and Use of DYNAGEM: A Dynamic Applied General Equilibrium Model for Policy Analysis.** By Xinshen Diao. Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture. Staff Paper No. 9903.


## Abstract

This report documents the Dynamic Applied General Equilibrium Model (DYNAGEM) developed at the U.S. Department of Agriculture's Economic Research Service to analyze issues of regional integration. In contrast with static CGE models, DYNAGEM endogenizes major intertemporal economic behavior, such as investment, savings, and international capital flows. The model can more satisfactorily analyze economic adjustment processes induced by a policy change in both the short- and medium-run. Here, the model is applied to NAFTA to illustrate the framework's ability to gauge policy impacts.



**Keywords**: Dynamic general equilibrium, U.S. agriculture, NAFTA

## Acknowledgments

The model development was part of the cooperative agreement between the Economic Research Service and the University of Minnesota, 1996-1997. The author has benefited from discussions with Jean Mercenier and Terry Roe. The author is also grateful to Tom Vollrath, Agapi Somwaru, Terri Raney, and Shayle Shagam for their help in writing this paper. The model was [illegible] applied to the NAFTA report, submitted to the U.S. Congress by U.S. Department of Agriculture in 1997, and the author has benefited from interaction with ERS's NAFTA team. The author is grateful to Praveen Dixit, Bill Kost, Terry Crawford, Mark Simone, Erinc Yeldan, Hunter Colby, Zhi Wang, and Carrie Ingoglia for their critical comments and suggestions. The author is responsible for any remaining error.





1800 M Street, NW
Washington, DC 20036-5831


June 1999

## Contents

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## Introduction

This report documents the Dynamic Applied General Equilibrium Model (DYNAGEM) developed by the Economic Research Service (ERS) and the University of Minnesota. The model has properties similar to other recent contributions found in the dynamic GE literature. See, for example, Ho (1989), McKibbin (1993), Mercenier and Sampaïo de Souza (1994), Go (1994), and Mercenier (1995).

The model documented in this report has already been used in a number of regional integration analyses within ERS, including the study on the Southern American Common Market (MERCOSUR) (Diao and Somwaru, 1999a and 1999b), North American Free Trade Agreement (NAFTA) (ERS/USDA, 1997) and the Free Trade Area of Americas (FTAA) (Diao and Somwaru, 1998). The model has also been used to examine the effects of the Asian crisis on the global economy (Diao, Li, and Yeldan, 1998), to ascertain the impacts of trade liberalization and water user-rights market on Moroccan agriculture (Diao and Roe, 1998), and to identify the outcomes of financial mismanagement on the Turkish economy (Diao, Roe, and Yeldan, 1999).

Specific features and structures of the model are presented and discussed. To illustrate its ability to diagnose policy impacts, the model is used to examine the effects of NAFTA, focusing on the economic adjustment processes in member countries during the first 3 years after its establishment.

## Overview of the Model

Applied (computable) general equilibrium (CGE) static models have been widely used as tools for trade reform and tax policy analyses for both developing and developed countries (see, for example, Shoven and Whalley, 1984; Cox and Harris, 1992; Brown, Deardorff, Stern, 1992; Dervis, de Melo and Robinson, 1992). But traditional static CGE models cannot capture intertemporal economic behavior in a theoretically consistent way. Past attempts to interject dynamics within static CGE models have been superficial: savings are assumed to be a fixed proportion of disposable income and investment is specified by "macro closures." The lack of theoretical foundations for such *intertemporal* decisions and the element of arbitrariness contained therein are clearly not consistent with the behavior of economic agents, which

otherwise are regarded as rational optimizers in the solution to their *intra-temporal* problems.[1]

In contrast with static models, the key feature of DYNAGEM is its ability to portray economic adjustment processes caused by a policy change in a theoretically consistent way. Consumption decisions are not made according to the household's current income, as is assumed in the static framework. Rather, consumption and saving decisions, which are jointly determined, are made intertemporally, and savings are generated for future consumption (fig. 1). By allowing for forward-looking behavior, DYNAGEM closely resembles the real economy and generates better results than static models in simulating policy changes.

On the supply side, producers make production and investment decisions both simultaneously and intertemporally in DYNAGEM. A decision on investment is, for example, not only determined by the current returns to capital, but is also determined by future returns. Similarly, a production decision in any given year is determined not only by price information in that year, but also by previous investment decisions.

The ability to account for investment decisions is particularly important. In the static CGE framework, resources (including capital) are fixed. Gains from trade liberalization or regional integration are generated only from more efficient reallocation of the current resources. As a result, the economic impacts of a policy change may be underestimated because the investment response is not taken into account. To overcome this shortcoming, some modelers adjust the capital stock exogenously in the static CGE framework. Arbitrarily adjusting the capital stock, however, not only departs from the economic theory, but embodies the modeler's subjectivity, biasing the empirical results.

DYNAGEM integrates both the commodity and capital markets (fig. 1), while the static model incorporates only the commodity markets. Commodity markets enable consumers to satisfy their consumption demand and allow producers to sell commodities, purchase intermediates, and make investments. The capital market allows consumers and producers to borrow and lend. Savings can then be channeled to investment in different sectors and across country borders.

DYNAGEM is a global model. All countries/regions in the world economy are characterized by their intertemporal economic behavior. The design of DYNAGEM allows it to be flexible in country/region coverage. In the NAFTA application, for example, the three member countries are specified, as well as four aggregate NAFTA trading partner groups. The model is also flexible in terms of sector specification. In the NAFTA application, agriculture is disaggregated into nine sectors, while non-agriculture is highly aggregated into three sectors.

Two factors are critical for understanding DYNAGEM and the empirical results presented in this paper. First, the model focuses on the real economy. It does not contain a monetary term. The

[1] This obvious inconsistency has not escaped the attention of many modelers; see, e.g., Srinivasan (1982), Bell and Srinivasan (1984), and Mercenier (1994).

focus on the real economy renders the model consistent with neoclassical macroeconomic and growth theories (see Barro, 1984; Barro and Sala-I-Martin, 1995; Obstfeld and Rogoff, 1996). As a result, the international financial capital market, and hence borrowing and lending among the countries, is characterized in the model by the real movements of commodities among the countries. This makes movement in the current account consistent with shifts in the trade account. Links between the capital market and commodity market will be further clarified in the next section.

Second, DYNAGEM cannot, itself, capture long-term economic growth. Total factor productivity growth and population growth are treated as exogenous variables in the neoclassic growth theory.[2] As the model is based upon this theory, the only way it can be used to analyze the long-term growth effects of a policy change is to incorporate econometric results of other studies.[3]

To further explain how the economic agents make their decisions and how policy change affects the model economy, the structure and major endogenous variables of the model are discussed in the following section. The technical description of the model can be found in Appendix I.

## Structure of DYNAGEM

In this section, the behavior of each economic agent in the model is described in a way that is consistent with the intertemporal economic theory, followed by a discussion of the market structure and equilibrium conditions.

### Producers' Decisions

Producers within each sector of a region are aggregated into a representative firm. Firms make production and investment decisions to maximize their intertemporal profit functions or the value of the firms. In making production decisions, the firms choose the levels of labor and intermediate inputs to produce a single sectoral output for each time period, taking into account the price of sectoral outputs, the wage rate, the prices of intermediate inputs, and the stock of capital at each time period. Sectoral outputs are either sold in the domestic market or exported to foreign markets.

In making investment decisions, firms have to compare the costs of investment with the expected future returns to capital, taking into account the price of investment goods and the interest rate in each time period. Firms are owned by households/consumers and investment is financed by undistributed profits. Borrowing by firms can be ignored because the number of the firms

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[2] See Grossman and Helpman (1991) for the further explanation and the contribution of the new (or endogenous) growth theory in this field.

[3] See, for example, the medium- and long-run effects of FTAA on the U.S. economy in Diao and Somwaru (1998).

remains constant with a constant returns to scale production technology. In each time period, the firm's profits, *div(n,i,t)* -- equivalent to the gross revenue minus labor costs, intermediate input costs, and investment costs -- distributed to households. Investment raises the stock of capital with waste caused by capital adjustment costs. Investment goods are purchased from other sectors, as well as from the firm's own forgone outputs. Investment goods can also be imported from abroad. Formally, the firm's problem can be described as follows:

$$Max\ V_{n,i,1} = \sum_{t=1}^{T} \frac{1}{\prod_{s=t}(1+r_s)^t} div_{n,i,t} + div_{n,i,T} \frac{(1+r_T)^{1-T}}{r_T} \tag{1}$$

$$div_{n,i,t} = PX_{n,i,t} X_{n,i,t} - \sum_j PC_{n,j,t} ITD_{n,j,i,t} - w_{n,t} LB_{n,i,t} - PI_{n,i,t} I_{n,i,t} [1 + \phi(\frac{I_{n,i,t}}{K_{n,i,t}}; a_{n,i})] \tag{2}$$

$$s.t.\ X_{n,i,t} = f(LB_{n,i,t}, K_{n,i,t}, ITD_{n,j_1,i,t}, ITD_{n,j_2,i,t}, \ldots, ITD_{n,j_J,i,t}) \tag{3}$$

$$K_{n,i,t+1} = (1 - \delta_{n,i}) K_{n,i,t} + I_{n,i,t}\ .\quad t = 1, 2, \ldots \tag{4}$$

In equation 1, $V_{n,i,1}$ represents the value of firm $i$ in country $n$ at the first time period; $1/\prod(1+r_s)^t$ is the discount factor for the future returns. In equation 2, $\phi(I/K;a)$ is the capital adjustment cost function. The choice variables for the firms are: (1) factor inputs of labor, *LB(n,i,t)*; (2) intermediate inputs, *ITD(n,i,j,t)*; (3) output, *X(n,i,t)*; (4) investment, *I(n,i,t)*; and (5) investment demand, *IVD(n,i,j,t)*. The set of $n$ in each variable represents region, $i$ and $j$ sector/commodity, and $t$ time. The number of variables, e.g., *ITD(n,i,j,t)*, is hence equal to $n$ x $i$ x $j$ x $t$. For example, if the model includes 7 regions, 12 sectors and 25 time periods, the number of potential intermediate input variables is 25,200, while the number of sector output variables equals 2,100. Besides these choice variables for firms, there are other endogenous variables which the model must solve. They include output price, *PX(n,i,t)*; price for intermediates, *PC(n,i,t)*; wage rate, *w(n,t)*; unit cost of investment, *PI(n,i,t)*; and world interest rate, *r(t)*.

**Households' Decisions**

In each region, the representative household owns land, labor, and all financial wealth, including the equity of domestic firms and foreign assets. Foreign assets are riskless, e.g., a foreign country's government bond. The households/consumers make consumption and saving decisions to maximize their intertemporal utility function over time. The total consumption expenditure (total current income minus current savings) and consumer demand for each individual commodity are determined simultaneously. However, the current consumption is not determined or constrained by consumer's current income because of savings. The intertemporal budget constraint prevents unlimited borrowing. Both borrowing and lending occur in the international capital market. Thus, if consumers' current consumption plus firms' investment are above the country's current income in an early period, there is international borrowing. In the future, the

country's consumption plus investment have to be below its future income, because the country is required to pay interests on the outstanding debt accumulated from borrowing.

## Government Policies

As the purpose of the model is to analyze policy response of the economy, the government is not modeled to make behavior decisions. It does not maximize any objective function. The government spends a fixed share of income on each commodity, and its total expenditure is constrained by its income. This implies that while the government's revenue and demand for each commodity are endogenously solved, the imbalance of the government budget has to be exogenously determined in the model.

The exclusion of government's behavioral decisions does not mean, however, that the government policies are ignored. All policy variables are exogenous in the model. They provide signals from which private agents make decisions. Major policy variables in DYNAGEM include import tariff rates and export subsidy rates, as well as some non-tariff barriers.

## World Commodity Markets and Exports/Imports

International trade flows are tracked by country/region of origin and destination. The variable $M(n,s,i,t)$ represents the trade flow of commodity $i$ from region $n$ to $s$ at time $t$ and is an endogenous variable in the model. As the sectors are quite aggregate (e.g., the sector of the non-grain crops is an aggregation of oilseed, cotton, sugar, and etc.), a country can export and import the same good simultaneously, i.e., $M(n,s,i,t)$ and $M(s,n,i,t)$ are different variables and may be both positive. For region $n$, $M(n,s,i,t)$ is its exports of good $i$ to region $s$, while $M(s,n,i,t)$ is region $n$'s imports of the same good from $s$. To capture such a two-way trade phenomenon, the Armington Assumption (Armington, 1969) is used in the model. That is, a good (e.g., wheat) sold to the domestic market (e.g., U.S. market) is not perfectly substitutable with the same good (wheat) imported from the international markets. Such an imperfect substitution relationship is also applicable to the same good (wheat) imported from different countries (e.g., Canada or Mexico). This implies that, for commodity $i$ and region $n$, the total imports, $MM(n,i,t)$, or exports, $EE(n,i,t)$, are functions of bilateral trade flows, i.e.,

$$MM(n,i,t) = f\,[M(s_1,n,i,t),\ M(s_2,n,i,t),\ ...,\ M(s_N,n,i,t)],$$

$$EE(n,i,t) = g\,[M(n,s_1,i,t),\ M(n,s_2,i,t),\ ...,\ M(n,s_N,i,t)],$$

where $N$ is the number of regions included in the model. This setup allows us to endogenously derive import demand for each commodity by country of origin and destination.

## World Capital Market and International Borrowing/Lending

International borrowing and lending occur in DYNAGEM. When a country's current consumption plus its investments are above its current domestic income, the country experiences

a trade deficit. If the reverse is true, the country experiences a trade surplus. If the country does not own net foreign assets that can generate income from abroad, the trade deficit has to be financed by international borrowing. Once international borrowing occurs, we observe foreign capital flowing into the country. The current period's foreign borrowing becomes a net debt burden and either increases the country's total outstanding debt or reduces its foreign assets, i.e.,

$$FB_{n,t} = \Sigma_i^J \Sigma_s^N (PWM_{s,n,i,t} M_{s,n,i,t} - PWM_{n,s,i,t} M_{n,s,i,t}) \tag{5}$$

$$B_{n,t+1} = (1 + r_t) B_{n,t} + FB_{n,t} \tag{6}$$

where *FB(n,t)* is a foreign trade deficit of region *n*, and *B(n,t)* is foreign debt. A negative *FB(n,t)* implies trade surplus for region *n*, while a negative *B(n,t)* is foreign assets for *n*. *FB(n,t)* and *B(n,t)* are both endogenous variables in the model, while the initial level of foreign assets or debt is given exogenously. It is clear that foreign debt in each region accumulates over time from trade deficits as well as interest payments on the outstanding debt. From equation 6, we can see that, once there exists foreign debt for a country at time *t*, the debt will accumulate over time, regardless of whether the country balances its trade in the following years, since it has to pay interest on its outstanding debt.

If we rearrange equation 6, we obtain the current account identity equation[4] as follows:

$$\Delta B_{n,t} = r_t B_{n,t} + FB_{n,t} \tag{6'}$$

A country's current account deficit (surplus) is equivalent to the net capital inflow (outflow), and thus the country increases its debt burden or reduces its foreign asset holdings.

It is clear from equation 6' that the unbalanced trade, $Fb_t$, is a major factor in determining the imbalance in the current account. However, the trade deficit (or surplus) is not the only factor to cause a current account deficit. Take Korea as an example. In 1990, Korea ran a trade surplus but a current account deficit, because Korea had to pay interest on its huge outstanding debt. The opposite occurred for the United States: in many years, the United States ran trade deficits but current account surpluses, because the United States owned net foreign assets during those years and earned enough income from abroad.

## Equilibrium Conditions

In DYNAGEM, once the demand for labor changes as a result of changes in sectoral production, the factor market is re-balanced and wage rates adjust. This occurs because the supply of labor, *LB(n)*, is equal to its total demand within regions under the assumption that factors are not mobile internationally, i.e.,

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[4] The adjustment in a country's foreign exchange reserves is ignored in equation 6.

$$\Sigma_i LB_{n,i,t} = \bar{LB}_n \qquad (7)$$

Thus, the wage rate, *w(n,t)*, for each region and each time period is endogenously determined by the labor market equilibrium condition in equation 7.

For the global model, all commodity markets have to clear. This equilibrium constraint implies that the world prices, *PWM(n,s,i,t)*, are endogenously determined in each time period, and a change in either demand for or supply of any commodity in a region would affect the world equilibrium and hence cause the world prices to adjust.

For the intertemporal model, the world financial capital market also has to clear, i.e., the world-wide sum of international borrowing and lending by individual countries is zero at any time. Moreover, the current account has to balance in the steady-state equilibrium in order to avoid a country's foreign debt from infinitely growing. That is, the left hand side of equation 6' has to be zero in the steady state. This implies that a country's intertemporal budget constraint is binding. It is clear from equation 6' that a balanced current account in the steady state requires that each country's foreign debt or assets be constant, and that there are no new foreign borrowing or lending activities along the steady-state equilibrium path. However, a balanced current account does not imply a balanced trade account. If a country borrows from abroad and hence runs a foreign debt, it has to run a trade surplus along the transitional path to the steady state in order to pay the interest costs on the debt. This intertemporal equilibrium condition allows us to calibrate the model parameters from a global database (such as the GTAP database) in which there are only flow data (i.e., there are no data for the stock of a country's foreign debt/assets). The calibration strategy can be found in Appendix II.

The intra- and inter-temporal equilibria of all endogenous variables in all regions and all time periods are solved simultaneously, such that a change in trade policy in one year not only affects the choices of agents in that year but also in all coming years. In sum, the model successfully endogenizes most economic decision variables over time while the number of exogenous variables is kept to a minimum.

## Data and Model Calibration

### The Data

The data for the model's calibration and for the "base-run" are drawn from the Global Trade Analysis Project (GTAP)[5] database, version 3, which typifies the world in 1992. GTAP database version 3 includes production and consumption data of 30 countries/regions on 37 commodities, as well as bilateral trade for each of the 37 commodities among the countries.

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[5] See McDougall (1997).

Aggregation of the GTAP database in DYNAGEM is quite flexible. For example, in the NAFTA application, the database was aggregated into 7 regions and 12 sectoral commodities. The seven countries or regions included in the model are: (1) the United States, (2) Canada, (3) Mexico, (4) the Rest of Western Hemisphere Countries, (5) the European Union, (6) Asian Countries, and (7) the Rest of the World. In each country or region, the 12 production activities and commodities are: (1) paddy and processed rice, (2) wheat, (3) other grains including corn, barley, and oats, (4) nongrain crops including fruits, vegetables, sugar, oilseeds, and cotton, (5) livestock, (6) meat products, (7) milk and dairy products, (8) beverages and tobacco products, (9) other processed food products, (10) manufacturing products, (11) trade and transportation services, and (12) other services.

**Calibration Method**

The calibration of the model involves specifying values for certain parameters obtained from external sources and deriving the remaining ones from restrictions posed by the equilibrium conditions. The demand elasticities of substitution between domestic and imported goods or among the goods imported from different countries of origin are obtained from the GTAP database. In addition, parameters related to intertemporal decisions are obtained from other macroeconomic studies.

The method used to calibrate parameters and initial values of variables associated with the intra-temporal economic activities involves standard processes used in static CGE modeling efforts. For example, to derive a Mexican import demand function for U.S. wheat, information about the share of U.S. wheat in Mexican total wheat imports is needed, as well as the substitution relationship between U.S. wheat and Canadian wheat. The share parameter, i.e., an expenditure share of each commodity by geographic origin in total expenditure on this commodity in a specific region, is calculated from these data. Discussion about the calibration strategy for the parameters or initial values of stock variables associated with intertemporal behaviors is in Appendix II.

**Policy Simulations**

The parameters of DYNAGEM, together with the levels of labor and land supply, the initial capital stock, and the initial trade deficit/surplus observed in the data for each country or region, serve as a starting point for the base run. If policies do not change, e.g., if NAFTA arrangements were not introduced into the model, then the model would exactly re-generate the base year (1992) data.

The economic impacts of regional trade agreements are analyzed by exogenously introducing a policy change into the model, for example, eliminating tariffs among member countries of a Regional Trade Arrangement (RTA). Producers and consumers respond to such a policy change by making a series of adjustments in their decision variables. Such adjustments occur simultaneously in the model and affect the whole price system, including world market prices for

each individual commodity, wage rates for each region, as well as expected returns to capital investment. These price changes generate, in turn, interlinkage effects between, for example, production and consumption or between imports and exports and so on. A new general equilibrium path for each endogenous variable is obtained from these interlinkage adjustments. Along the transitional path for each variable, its value for each time period is also obtained. The effect of the policy change on any endogenous variable is obtained from the comparison between its new value and its base-year value.

In the following section, the economic impacts of NAFTA are discussed by using this model. The purpose is to illustrate how DYNAGEM can be used in policy analysis. Therefore, not all model results are reported here.

## Empirical Application of DYNAGEM

DYNAGEM has been used in several applications at ERS, including evaluating MERCOSUR, NAFTA, and the FTAA. The remainder of this report will document the use of DYNAGEM for NAFTA analysis. Detailed model results and their relevance to actual changes are published in an ERS NAFTA report (USDA, ERS, 1997).

The North American Free Trade Agreement (NAFTA) came into effect on January 1, 1994, and set in motion the elimination of all tariff and many nontariff barriers within 15 years of implementation for Canada, Mexico, and the United States. NAFTA captivated the attention of many researchers before its implementation because of its strategic importance. These researchers identified the potential policy impacts of NAFTA (see related references in USDA, ERS, 1997). Since NAFTA has gone into effect, however, few research efforts have been devoted to tracking or analyzing how NAFTA has, in fact, affected its member countries' economies. Three years of observable data are now available. Most of the available literature which attempts to describe post-NAFTA economic changes can be categorized as reviews of the trends and events. They do not explain the economic mechanisms underlying these changes (e.g., IDB, 1996; UNECLAC, 1996; USITC, 1996; USTR, 1996).

Numerous debates have been taking place among economists about methodological approaches for predicting what might be the impacts of regional trade agreements on member countries' employment and social welfare. These debates have served to advance the development of new tools and techniques in policy-relevant research, focusing attention on accurately determining the dimensions of possible short- and long-term impacts of trade liberalization and regional integration (see, e.g., Hinojosa-Ojeda et al., 1992; Abler and Pick, 1993; Burfisher et. al., 1993; Shiells, 1993; Srinivasan, et al., 1993; Baer and Weintraub, 1994; Francois and Shiells, 1994; Imada-Iboshi and McCleery, 1994; Roland-Holst et al.,1994; Devadoss, et al., 1995; Rivera, 1995; Bolle, 1996; and Gould, 1996).

**Table 1 -- Tariff rates among the NAFTA countries, 1992**

| | U.S. imports from | | Canadian imports from | | Mexican imports from | |
|---|---|---|---|---|---|---|
| | Canada | Mexico | USA | Mexico | USA | Canada |
| | *Percent of import value at the world price* | | | | | |
| Paddy and processed rice | 5.73 | 13.26 | 4.79 | 8.27 | 4.80 | |
| Wheat | 28.03 | 5.45 | 14.02 | 5.38 | 13.00 | |
| Other grains | 26.12 | 9.24 | 0.44 | 9.12 | 2.74 | |
| Nongrain crops | 38.41 | 3.48 | 50.36 | 3.44 | 68.64 | 3.44 |
| Livestock | 0.33 | 0.01 | 1.09 | 0.00 | 1.54 | |
| Meat products | 28.29 | 21.44 | 14.15 | 21.18 | 14.29 | 28.25 |
| Other food products | 4.89 | 16.49 | 2.18 | 16.29 | 7.49 | 5.67 |
| Milk products | 180.25 | 0.00 | 105.63 | | 106.70 | |
| Beverages and tobacco | 9.82 | 19.70 | 3.14 | 19.45 | 7.31 | 1.79 |
| Other manufacturing goods | 1.41 | 10.42 | 0.34 | 9.63 | 5.16 | 6.80 |

NAFTA has just completed its fourth year. The initial years of NAFTA implementation have been characterized by significant, concurrent changes in domestic agricultural policies of the United States, Canada, and Mexico, and in the global trade policy environment for agriculture. The Mexican peso crisis and economic recession in 1995, together with other unexpected factors, overwhelmed the effects of the early tariff reductions under NAFTA in many cases and affected trade in a number of commodities in the North American market. Therefore, it was necessary to separate the pure NAFTA trade effects from the impacts of the other external forces. To accomplish this, 1992 data and applied trade protection policies from the database (table 1) were used as a proxy for levels of investment and employment pre-NAFTA. Then, the tariff rates were reduced according to the NAFTA timetable in its first 3 years (table 2). The scenario captures NAFTA's tariff reduction schedules but left the nontariff barriers untouched.[6] Thus, the economic adjustments due to NAFTA in the three member economies to date are observed by the differences between the solved results for the endogenous variables obtained from the policy experiment and their initial values in the data.

The overall impact of the NAFTA simulation in the model is modest for each of the three countries in the first 3 years, while the benefits are consistently positive for all three economies (table 3). The modest size of the impacts is not surprising because the tariff reductions in the simulation are small, which is consistent with NAFTA's real situation in its first 3 years. Such small tariff reductions do not have significant influences on investment and employment, even in an intertemporal model. In the model, 3 years into NAFTA, investment increases by only 0.02 percent in the United States, 0.1 percent in Canada and 0.8 percent in Mexico, compared with

[6] Due to the data limitation about the quantitative restriction, liberalization of the nontariff barriers, which is part of NAFTA, is not taken into account in the model. Hence, the model results may understate the effects of NAFTA.

what would have happened without the agreement. Thus, the simulation results also show small positive change in each member country's welfare, measured by either the growth in a country's real GDP or change in the welfare equivalent variation.

**Table 2 -- Tariff rates among the NAFTA countries, 1996**

| | U.S. imports from | | Canadian imports from | | Mexican imports from | |
|---|---|---|---|---|---|---|
| | Canada | Mexico | USA | Mexico | USA | Canada |
| | *Percent of import value at the world price* | | | | | |
| Paddy and processed rice | 5.45 | 12.60 | 4.55 | 7.86 | 4.56 | 0.00 |
| Wheat | 26.63 | 5.17 | 13.32 | 5.11 | 12.35 | 0.00 |
| Other grains | 22.98 | 8.12 | 0.34 | 7.30 | 2.47 | 0.00 |
| Nongrain crops | 32.26 | 2.96 | 41.80 | 2.85 | 61.78 | 3.09 |
| Livestock | 0.28 | 0.00 | 0.90 | 0.00 | 1.40 | 0.00 |
| Meat products | 24.05 | 18.01 | 11.60 | 17.37 | 12.86 | 25.14 |
| Other food products | 3.82 | 12.86 | 1.67 | 12.54 | 6.73 | 5.11 |
| Milk products | 178.40 | 0.00 | 104.58 | 0.00 | 106.70 | 0.00 |
| Beverages and tobacco | 7.66 | 15.17 | 2.42 | 14.98 | 6.43 | 1.51 |
| Other manufacturing goods | 1.06 | 7.81 | 0.27 | 7.71 | 4.13 | 5.44 |

The effects of tariff reductions on NAFTA member countries' trade are large relative to other impacts. The simulation results show that total exports are about 0.3, 0.5, and 2 percent higher, respectively, in the United States, Canada, and Mexico, than they would have been without the agreement. Similarly, total imports by the United States, Canada and Mexico are about 0.3, 0.5, and 2.1 percent higher, respectively, than they would have been without NAFTA. Products having the highest tariff barriers before the agreement and facing significant reductions in the simulation are those that have experienced the biggest trade changes due to NAFTA.

**Table 3 -- Change in NAFTA countries' major economic indicators due to NAFTA, 1996**

| | U.S. | Canada | Mexico |
|---|---|---|---|
| | *Percent change from 1992* | | |
| Real GDP[1] | 0.001 | 0.005 | 0.034 |
| Total real investment | 0.023 | 0.101 | 0.789 |
| Total consumption | 0.021 | 0.093 | 0.215 |
| Average wage | 0.065 | 0.050 | 0.065 |
| Welfare index[2] | 0.011 | 0.045 | 0.107 |
| Total exports | 0.313 | 0.451 | 2.032 |
| Total imports | 0.291 | 0.497 | 2.131 |
| Trade deficit[3] | -0.057 | N/A | 2.582 |
| Trade surplus | N/A | -0.829 | N/A |
| Current account[4] | -2.309 | 4.897 | 38.111 |

[1] GDP growth is in per capita terms and technical progress is not taken into account.
[2] The welfare index is measured by the equivalent variation which takes into account both the short- and long-run effects of NAFTA.
[3] The negative sign implies trade deficit reduction.
[4] The negative sign indicates a current account surplus which implies capital inflows, while a positive sign indicates a current account deficit.

**Impacts of NAFTA on Investment in U.S. Agriculture and Rural Areas**

The adjustment path of investment generated by DYNAGEM is much smoother than what might happen in the real world. In the model, two types of investment adjustments occur. First, the total investment rises due to an expectation for a rise in future returns from capital after NAFTA. Then, the allocation of investment among different production sectors adjusts, and investment mainly occurs in the most competitive sectors.

Agricultural investment is a small portion of total investment within NAFTA. The data show that in 1992, agricultural investment accounted for 5.9 percent of total investment in the United States, 6.4 percent in Canada, and 11.5 percent in Mexico. In the modeling framework, the three economies first begin to adjust in 1993, the year after the agreement was formally ratified and before implementation began. The model shows both the level of total investment in the economy and the share of investment going to agriculture rising slightly. By 1996, the total investment (in real terms) rises, according to the simulation results, by less than 0.1 percent in the United States and Canada and 0.8 percent in Mexico (table 3). The share of total investment going to agriculture increases slightly in the three countries, compared with what would have happened without NAFTA.

As both total investments and the agricultural share rise, investment in agriculture also rises

(table 4). For the United States, the investment measured by the base-year price level in agriculture and related sectors increases 0.2 percent in 1996 compared with what would have occurred without NAFTA. Investment growth in the United States is highest in crop production and processed food products, but livestock production gains as well. Investment in the Canadian agricultural sector increases slightly more, 0.7 percent, with large gains in the livestock and beverages sectors. For Mexico, the overall increase in investment in agriculture and related sectors is somewhat higher at 0.9 percent, with the largest gains in the crops sector and beverages and tobacco sector.

With an increase in capital investment, a country's domestic savings, i.e., a country's national income minus its consumers' final consumption, may not be enough to finance the investment. Thus, the rise in investment has to be partially financed by foreign capital inflows. In the model, we observe that, as Mexico's capital investment rises more rapidly, there are foreign capital inflows into the country.

The existence of an international financial capital market in the model implies that U.S. investment opportunity is not limited by country border. Foreign capital inflows into Mexico may imply a rise in foreign assets for U.S. households or an increase in foreign investment for U.S. firms. With the perfect international capital market assumption, DYNAGEM cannot tell the difference between foreign direct investment and indirect investment through financial arrangements. However, the model simulation results show that the United States and Canada are the major suppliers of foreign capital for the rise in Mexico's investment due to NAFTA. These results are consistent with the strong record of U.S. food processing companies operating in Mexico and Canada as indicated by empirical data.

Increased investment in Mexico further raises import demand for U.S. capital goods. The base year data indicate that imports of capital goods from the United States accounted for 70 percent of the Mexican imports of capital goods. As investment rises in Mexico, the simulation results show that Mexico increases imports of capital goods from the United States by 4 percent in 1996 due to NAFTA.

**Table 4 -- Change in investment by sector due to NAFTA, 1996**

| | U.S. | Canada | Mexico |
|---|---|---|---|
| | *Percent change from 1992 in real terms* | | |
| Agriculture and related sectors | 0.19 | 0.67 | 0.91 |
| Crops | 0.36 | -0.06 | 1.55 |
| Livestock | 0.14 | 1.04 | 0.60 |
| Processed food products | 0.19 | 0.68 | 0.67 |
| Beverages and tobacco | 0.06 | 1.10 | 1.17 |
| Other manufacturing | 0.05 | 0.14 | 1.92 |
| Trade and transportation | 0.04 | 0.10 | 0.55 |
| Other services | -0.01 | 0.01 | -0.22 |

## Impacts of NAFTA on Employment in U.S. Agriculture

In order to endogenously determine the wage rate, the model assumes that the supply of labor is equal to the total demand for labor employed in each region. However, labor can move across sectors within a region, and employment would be expected to fall in those sectors where output declines and to grow in those sectors where output expands.

The simulation results show that the greatest rise in employment in the United States is in nongrain crops, livestock and meat-related industries, and other processed food products. This implies that NAFTA would stimulate employment growth in the United State sectors providing high-value products for export to Canada and Mexico. The change in Canada's rural employment in the simulation is similar, that is, employment in agriculture and agriculture-related industries rises slightly. The greatest rise would be expected in livestock and meat-related industries and beverage and tobacco industries, while the employment would fall for nongrain crops. In Mexico, the employment level rises only in nongrain crops, and falls in all other agricultural and agriculturally related industries.

**Table 5 -- Change in sectoral labor demand due to NAFTA, 1996**

| | U.S. | Canada | Mexico |
|---|---|---|---|
| | *Percent change from 1992* | | |
| Grain crops | 0.062 | 0.193 | -0.138 |
| Rice | 0.048 | 0.009 | -0.386 |
| Wheat | -0.104 | 0.235 | -0.216 |
| Other grains | 0.098 | 0.120 | -0.117 |
| Nongrain crops | 0.213 | -0.442 | 0.426 |
| Livestock | 0.058 | 0.710 | -0.103 |
| Meat products | 0.069 | 0.670 | -0.201 |
| Other processed food products | 0.071 | 0.361 | -0.136 |
| Milk products | 0.011 | 0.332 | -0.190 |
| Beverages and tobacco | -0.006 | 0.605 | 0.097 |
| **Aggregate agricultural labor** | 0.070 | 0.360 | 0.090 |

## Impacts of NAFTA on U.S. Agricultural Trade

In general, a free-trade area in which tariffs are lowered or eliminated among its member countries creates trade opportunities for members. However, as most tariffs in agricultural trade among the United States, Canada, and Mexico were relatively low before NAFTA, and tariffs are only partially reduced in the simulation, large changes in trade flows are unlikely.

The model results indicate that exports of U.S. agricultural goods to Mexico and Canada are about 3 and 7 percent higher, respectively, and imports from Mexico and Canada are about 3 and 5 percent higher, respectively, in 1996 than they would have been without the agreement (table 6). In total, U.S. agricultural and agriculture-related exports to the world are about 1 percent higher than they would have been without NAFTA. Canada's total agricultural exports increase about 3 percent, while Mexico's total agricultural exports rise by 2 percent, compared with what they would have been without NAFTA.

Increase in trade among the member countries contributes to the expansion of their total trade, while trade with third countries may fall. The model results indicate that U.S. agricultural exports to the rest of the world are 0.2 percent lower than they would have been without NAFTA. Canada slightly increases its agricultural exports to the rest of the world (by 0.06 percent), while Mexico reduces its exports to the rest of the world by 3 percent, compared with what they would have been without NAFTA. Detailed results about the changes in exports and imports of major agricultural sectoral goods of the three member countries due to NAFTA are presented in table 6.

**Table 6 -- Change in NAFTA member countries' trade due to NAFTA, 1996**

| | U.S. | | Canada | | Mexico | |
|---|---|---|---|---|---|---|
| | Exports | Imports | Exports | Imports | Exports | Imports |
| | *Percent change from 1992* | | | | | |
| Total agricultural products | 0.82 | 0.70 | 2.87 | 2.35 | 2.26 | 2.33 |
| Paddy and processed rice | -0.05 | 0.19 | 0.80 | 0.26 | -2.14 | 1.31 |
| Wheat | -0.26 | 1.50 | 0.24 | 2.52 | 0.00 | 1.34 |
| Other grains | 0.08 | 0.36 | 0.37 | 5.34 | -2.23 | 1.76 |
| Nongrain crops | 1.56 | 1.32 | 7.03 | 6.33 | 4.06 | 2.07 |
| Livestock | -0.14 | 0.67 | 1.75 | -0.25 | -2.02 | 1.15 |
| Meat products | 1.60 | 1.45 | 7.14 | 4.88 | 0.14 | 3.85 |
| Other processed food products | 0.77 | 0.42 | 1.55 | 1.28 | 0.90 | 3.22 |
| Milk products | 0.08 | 1.81 | 0.45 | 0.28 | -1.89 | 0.90 |
| Beverages and tobacco | 0.08 | 0.56 | 3.31 | 1.53 | 1.04 | 2.48 |
| Total nonagricultural products | 0.25 | 0.22 | 0.32 | 0.29 | 2.07 | 1.57 |
| Manufacturing | 0.26 | 0.37 | 0.40 | 0.34 | 2.37 | 2.51 |
| Trade and transportation | 0.03 | -0.12 | -0.06 | 0.02 | 0.82 | -1.49 |
| Other services | 0.08 | -0.13 | -0.09 | 0.07 | 0.74 | -1.47 |

| | U.S. exports to | | Canadian exports to | | Mexican exports to | |
|---|---|---|---|---|---|---|
| | Canada | Mexico | U.S. | Mexico | U.S. | Canada |
| Total agricultural products | 7.12 | 3.02 | 5.21 | 2.89 | 3.24 | -7.14 |
| Paddy and processed rice | 0.5 | 2.3 | 1.38 | 1.93 | 0 | 0 |
| Wheat | 2.52 | 1.17 | 1.51 | 1.6 | 0 | 0 |
| Other grains | 5.72 | 1.77 | 0.52 | 2.22 | -1.14 | 0 |
| Nongrain crops | 11.9 | 2.63 | 23.82 | 1.67 | 5.3 | -10.78 |
| Livestock | -0.27 | 1.03 | 1.87 | 2.47 | -2.02 | -2.63 |
| Meat products | 9.41 | 4.13 | 9.68 | 10.79 | 2.47 | 3.4 |
| Other processed food products | 2.86 | 4.48 | 2.33 | 4.99 | 1.38 | -0.64 |
| Milk products | 2.34 | 0.68 | 2.5 | 1.07 | -1.79 | 0 |
| Beverages and tobacco | 11.27 | 7.43 | 3.94 | 7.42 | 2.22 | -2.29 |
| Total nonagricultural products | 0.69 | 3.14 | 0.36 | 3.07 | 2.82 | 3.5 |
| Manufacturing | 0.92 | 3.77 | 0.39 | 3.74 | 3.54 | 4.56 |
| Trade and transportation | -0.1 | 0.75 | 0.14 | 0.91 | -1.36 | -1.44 |
| Other services | -0.15 | 0.68 | 0.11 | 0.88 | -1.45 | -1.52 |

## Conclusions

This report documents the Dynamic Applied General Equilibrium Model (DYNAGEM) that has been used within ERS to examine the economic impacts of regional trade agreements. In contrast with static CGE models, DYNAGEM endogenizes forward-looking economic behavior, such as investment, savings, and international capital flows. The model is global and flexible in country/region coverage. All countries/regions are characterized by their intertemporal economic behavior. Consequently, DYNAGEM is better able to analyze economic adjustment processes induced by a policy change in both the short- and medium-run.

Results emanating from a dynamic applied GE model like DYNAGEM have to be kept in perspective for a number of reasons. First, DYNAGEM is a simulation model. Consequently, the policy experiments are *comparative* in nature--they are meaningful only in relation to the base run. DYNAGEM cannot generate forecasts of the future.

Second, both the consumption and production activities of the economy are modeled in very aggregate terms. DYNAGEM embodies the *representative* national consumer. This level of aggregation, though a common device in modern macroeconomic thinking, excludes analyses of income distribution or issues related to the heterogeneity of the private sectors. Similarly, the model does not incorporate government saving and investment behavior. Hence, it cannot capture spillover effects of public consumption and investment on the private sector.

Third, the simulation exercises of DYNAGEM reflect *equilibrium* relationships based upon a *smooth* time horizon. Thus, the speed of transitional adjustment of many variables to their equilibrium paths should not be taken as a measure of the global stability properties of the modeled economies, but rather as a direct outcome of the laboratory characteristics of a GE model with well-behaved functional forms and without any rigidity or structural bottleneck.

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## Appendix I. The Mathematical Presentation of DYNAGEM

Most of the following equations are included in the model solved by the General Algebraic Modeling System (GAMS).[7]

### The Producers' Decisions

The representative firms in each sector of each region maximize the intertemporal profits (or the value of the firm), subject to the technology and capital accumulation constraints:

$$Max\ V_{n,i,1} = \sum_{t=1}^{T} \frac{1}{\prod_{s=t}(1+r_s)^t} div_{n,i,t} + div_{n,i,T}\frac{(1+r_T)^{1-T}}{r_T} \qquad \text{(A1)}$$

$$div_{n,i,t} = PVA_{n,i,t}X_{n,i,t} - w_{n,t}LB_{n,i,t} - PVA_{n,i,t}\phi_{n,i}\frac{I^2_{n,i,t}}{K_{n,i,t}} - PI_{n,i,t}I_{n,i,t} \qquad \text{(A2)}$$

$$s.t.\ X_{n,i,t} = A_{n,i}\,LB_{n,i,t}^{\alpha_{n,i,lb}}\,K_{n,i,t}^{\alpha_{n,i,k}} \qquad \text{(A3)}$$

$$K_{n,i,t+1} = (1-\delta_{n,i})K_{n,i,t} + I_{n,i,t} \qquad \text{(A4)}$$

$$I_{n,i,t} = A_{n,i,k}\prod_j^J IVD_{n,j,i,t}^{d_{n,j,i}}\ .\quad t = 1, 2, \ldots \qquad \text{(A5)}$$

where

$V_{n,i,t}$ value of firm,
$div_{n,i,t}$ net profit (dividend),
$PVA_{n,i,t}$ unit value added,
$X_{n,i,t}$ output,
$w_{n,t}$ wage rate,
$LB_{n,i,t}$ labor employed by sector,
$K_{n,i,t}$ capital in sector
$I_{n,i,t}$ investment in quantity,
$PI_{n,i,t}$ unit value of capital investment,
$IVD_{n,j,i,t}$ investment demand for good,
$r_t$ world interest rate;
$A_{n,t}$ parameter of technological level in value added function,
$A_{n,i,k}$ parameter of technological level in investment function,
$\alpha_{n,i,f}$ share parameter in value added production function for factor,

[7] See Brooke, Kendrick, and Meeraus, 1988.

$d_{n,j,i}$ share parameter in investment production function for good,
$\phi_{n,i}$ parameter in capital adjustment function,
$\delta_{n,i}$ constant capital depreciation rate.

The first-order conditions for a firm's problem are:

$$\alpha_{n,i,l} PVA_{n,i,t} X_{n,i,t} = w_n LB_{n,i,t} \quad \text{(A6)}$$

$$q_{n,i,t} = PI_{n,i,t} + 2PVA_{n,i,t}\phi_{n,i}\frac{I_{n,i,t}}{K_{n,i,t}} \quad \text{(A7)}$$

$$(1+r_t)q_{n,i,t-1} = \alpha_{n,i,k} PVA_{n,i,t}\frac{X_{n,i,t}}{K_{n,i,t}} + PVA_{n,i,t}\phi_{n,i}\left(\frac{I_{n,i,t}}{K_{n,i,t}}\right)^2 + (1-\delta_{n,i})q_{n,i,t} \quad \text{(A8)}$$

where $q_{n,i,t}$ is marginal value (Tobin's q) of capital. Given the price system, equations A6-A8, together with equations A2-A4 can be used to solve for the supply of sectoral outputs, sectoral demand for labor and land, sectoral investment and capital stock, as well as sectoral dividends over time for each region. The investment demand for final goods employed in the new physical capital production is:

$$IVD_{n,i,j} = \frac{d_{n,i,j} PI_{n,j} I_{n,j}}{PC_{n,i}} \quad \text{(A9)}$$

and the demand for intermediate inputs is:

$$ITD_{n,j,i,t} = IO_{n,j,i} X_{n,i,t} \quad \text{(A10)}$$

and hence the producer prices are:

$$PX_{n,i,t} = PVA_{n,i,t} + \Sigma_j PC_{n,j,t} IO_{n,i,j,t} \quad \text{(A11)}$$

where

$ITD_{n,j,i,t}$ intermediate demand for good,
$PC_{n,i,t}$ composite price for demanders,
$PX_{n,i,t}$ producer price,
$IO_{n,i,j}$ input-output coefficient.

## The Households' Decisions

The representative household/consumer in each region maximizes the intertemporal utility over time and subject to the intertemporal budget constraint:

$$Max\ U_{n,1} = \Sigma_{t=1}^{T} (\frac{1}{1+\rho})^t \ln(TC_{n,t}) + \ln(TC_{n,T}) \frac{(1+\rho)^{1-T}}{\rho} \quad (A12)$$

$$(A13)$$

$$TC_{n,t} = \Pi_i CD_{n,i,t}^{b_{n,i}} \quad (A14)$$

$$s.t.\ \Sigma_i PC_{n,i,t} CD_{n,i,t} = Y_{n,t} - SAV_{n,t} \quad (A15)$$

$$Y_{n,t} = wl_{n,t} \bar{LB}_n + wd_{n,t} \bar{LD}_n + \Sigma_i div_{n,i,t} + GT_{n,t} - r_t B_{n,t} \quad (A16)$$

where

$TC_{n,t}$ household aggregate consumption,
$CD_{n,i,t}$ household demand for good,
$Y_{n,t}$ household income,
$SAV_{n,t}$ household savings,
$B_{n,t}$ foreign debt,
$GT_{n,t}$ government transfer,
$LB_{n,t}$ labor supply,
$LD_{n,t}$ land supply,
$\rho$ rate of consumer time preference,
$b_{n,i}$ share parameter in household demand function.

The first-order conditions for the consumer's problem are:

$$\frac{Y_{n,t+1} - SAV_{n,t+1}}{Y_{n,t} - SAV_{n,t}} = \frac{1 + r_{t+1}}{1 + \rho} \quad (A17)$$

$$CD_{n,i,t} = \frac{b_{n,i}(Y_{n,t} - SAV_{n,t})}{PC_{n,i,t}} \quad (A18)$$

Given the price system and each element of the household's current income, equations A17 and A18, together with equations A13-A16 can be used to solve for the levels of the consumer's total consumption, demand for each commodity, and savings.

**Government Consumption Demand**

$$PC_{n,i,t}GD_{n,i,t} = c_{n,i,t}(\Sigma_i\Sigma_s te_{n,s,i,t}PWM_{n,s,i,t}M_{n,s,i,t} + \Sigma_i\Sigma_s tm_{s,n,i}PWM_{s,n,i,t}M_{s,n,i,t} - GT_{n,t}) \quad \text{(A19)}$$

where

$GD_{n,i,t}$ government demand,

$M_{n,s,i,t}$ trade flow,

$tm_{s,n,i,t}$ tariff rate,

$te_{n,s,i,t}$ export tax rate,

$c_{n,i}$ share parameter in government demand function.

Government consumption demand is proportional to its current revenue, which equals tariff/tax incomes from the country's total imports/exports, minus transfers to households. The indirect income tax revenues are not presented here but are included in the model.

**Exports and Imports**

The demand for goods consumed by consumers and the government, and used in investment process or as intermediates, are generated from the two levels of Armington functions:

$$MM_{n,i,t} = \Upsilon_{n,i}[\Sigma_s \theta_{s,n,i} M_{s,i,t}^{(\sigma m_{n,i} - 1)/\sigma m_{n,i}}]^{\sigma m_{n,i}/(\sigma m_{n,i} - 1)} \quad \text{(A20)}$$

$$C_{n,i,t} = \Lambda_{n,i}[\beta_{n,i} MM_{n,i,t}^{(\sigma mm_{n,i} - 1)/\sigma mm_{n,i}} + (1 - \beta_{n,i}) D_{n,i,t}^{(\sigma mm_{n,i} - 1)/\sigma mm_{n,i}}]^{(\sigma mm_{n,i} - 1)/\sigma mm_{n,i}} \quad \text{(A21)}$$

where

$MM_{n,i,t}$ composite import good,

$C_{n,i,t}$ total absorption of composite good,

$D_{n,i,t}$ good *i* produced and consumed domestically,

$\Upsilon_{n,i}$ shift parameter in Armington import function,

$\Lambda_{n,i}$ shift parameter in Armington composite function,

$\theta_{s,n,i}$ share parameter in Armington import function,

$\beta_{n,i}$ share parameter in Armington function for composite good,

$\sigma m_{n,i}$ elasticity of substitution in Armington import function,

$\sigma mm_{n,i}$ elasticity of substitution in Armington composite function.

Equation A20 generates a composite sectoral import good for each region, while equation A21 generates a composite sectoral good for each region. Consumers and the government in each region consume the composite goods, so do investment and intermediate demand.

Demand functions for imports and domestically produced goods are derived from minimizing current expenditure, subject to equation A20 and A21. The first-order conditions for this problem are:

$$M_{s,n,i,t} = \Upsilon_{n,i}^{\sigma m_{n,i}-1} \left[\frac{\theta_{s,n,i} PMM_{n,i,t}}{((1+tm_{s,n,i,t})/(1-te_{s,n,i,t}))\, PX_{s,i,t}}\right]^{\sigma m_{n,i}} MM_{n,i,t} \tag{A22}$$

$$MM_{n,i,t} = \Lambda_{n,i}^{\sigma mm_{n,i}-1} \left[\beta_{n,i} \frac{PC_{n,i,t}}{PMM_{n,i,t}}\right]^{\sigma mm_{n,i}} C_{n,i,t} \tag{A23}$$

$$D_{n,i,t} = \Lambda_{n,i}^{\sigma mm_{n,i}-1} \left[(1-\beta_{n,i}) \frac{PC_{n,i,t}}{PX_{n,i,t}}\right]^{\sigma mm_{n,i}} C_{n,i,t} \tag{A24}$$

where $PMM_{n,i,t}$ is composite import price.

Equations A20-A24 determine import demand and demand for domestically produced goods by sectors and regional origin and destination.

**Foreign Borrowing and Foreign Debt**

$$FB_{n,t} = \Sigma_i \Sigma_s \left(\frac{PX_{n,i,t}}{1-te_{s,n,i,t}} M_{s,n,i,t} - \frac{PX_{s,i,t}}{1-te_{n,s,i,t}} M_{n,s,i,t}\right) \tag{A25}$$

$$B_{n,t+1} = (1+r_t)B_{n,t} + FB_{n,t} \tag{A26}$$

where $FB_{n,t}$ is a foreign trade deficit of region $n$. Foreign debt in each region is accumulated over time from trade deficits and interest payments on the outstanding debt.

### Factor Market Equilibrium Conditions within Regions

$$\sum_i LB_{n,i,t} = \bar{LB}_n \tag{A27}$$

$$\sum_i LD_{n,i,t} = \bar{LD}_n \tag{A28}$$

These two equations in each region determine the wage rate and land rental price for the region.

### Commodity Market Equilibrium Conditions

$$C_{n,i,t} = CD_{n,i,t} + GD_{n,i,t} + \sum_j IVD_{n,i,j,t} + \sum_j ITD_{n,i,j,t} \tag{A29}$$

This equation determines the equilibrium price, $PC_{n,i,t}$, for demanders in each region.

It should be noted that Equations A2-A11, A13-A29 all have a time dimension. Hence, if the subscripts for the variables in the equations are *I*, *n*, *t*, then one equation above represents *i* x *n* x *t* equations in the model.

### Terminal Conditions (the Steady-State Constraints)

The terminal conditions are imposed in the model, such that when the time is beyond *T*, which is the last time period in the model, all endogenous variables are approached approximately to their steady-state situation. For this reason, the steady-state constraints have to be satisfied for the equations defined as terminal conditions, i.e.,

$$\delta_{n,i} K_{n,i,T} = I_{n,i,T} \tag{A30}$$

$$r_T V_{n,i,T} = div_{n,i,T} \tag{A31}$$

$$r_T B_{n,T} + FB_{n,T} = 0 \tag{A32}$$

$$r_T = \rho \tag{A33}$$

Equation A30 implies that, at the steady state, investment just covers the depreciated capital; hence the stock of capital per labor remains constant in each region. Equation A31 states that the dividend of the firms is equal to the interest income earned from the same amount of financial

capital. Equation A32 states that foreign debt/assets is constant for each region. Hence, if an economy experiences debt in the steady state (i.e., $B_{nT}$ is positive), then it has to have a trade surplus to pay interest, i.e., $FB_{nT}$ has to be negative. Equation A33 implies that the world interest rate is constant in the steady state and equals the time discount rate in the utility function.

**Welfare Criterion (Equivalent Variation Index)**

$$\Sigma_{t=0}^{\infty}\left(\frac{1}{1+\rho}\right)^t \ln(\hat{TC}_n(1+\varphi_n)) = \Sigma_{t=0}^{\infty}\left(\frac{1}{1+\rho}\right)^t \ln(TC_{nt}) \quad \text{(A34)}$$

where $\hat{TC}_n$ is the base year's total consumption. That is, the welfare gain over time resulting from the policy change is equivalent to increasing the reference consumption profile by $\varphi_n$ percent.

## Appendix II. Calibration Strategy

Calibration of the model involves specifying values for certain parameters based on outside estimates and deriving the remaining ones from restrictions posed by the equilibrium conditions. As in a static CGE model where calibration begins with the assumption that data obtained for the domestic economy reflect a within time period equilibrium, in DYNAGEM the world is assumed to be evolving along a balanced (equilibrium) growth path.[8] In counter factual experiments, this specification can be regarded as robust since the model is interested in deviations with respect to a reference path.

The method used to calibrate parameters or initial values of variables associated with intra-temporal economic activities involve standard processes used in static CGE modeling efforts. The more subtle dynamic calibration is sketched here. Starting from the steady-state assumption, the household time discount rate, ρ, equals the world interest rate, $r$, which can be chosen from outside data, while a country's foreign assets or debt are determined by equation A32 once the trade deficits or surplus are obtained from the database. The GTAP database provides both the values of each region's stock of capital and the flows of capital. Using these data, together with the data of the value of total investment, it is easy to calculate the initial level of total dividend payments (*div = value of capital flows - value of total investment*). The steady-state value of the firms, $V$, and hence the marginal value of capital, Tobin's q, are then obtained, i.e., $V = div/r$; $q = V/K$. The values of capital depreciation rate, δ, and the coefficient in the capital adjustment costs, ϕ, have to be chosen consistently with the steady-state condition. We can choose either δ or ϕ and then calculate the other one from the steady-state conditions presented in the section

[8] The steady-state assumption, though questionable for most developing economies, is systematically adopted in applied intertemporal general equilibrium models due to its extreme convenience for calibration. See, for example, Goulder and Summers (1989), Go (1994), and Mercenier and Yeldan (1997).

"Overview of the Model." If $\phi$ is chosen first, then $\delta$ is calculated from the following equation derived from the steady-state conditions:

$$\delta = \frac{q}{2P\phi} - \left[\frac{rq - wk}{P\phi} + \left(\frac{q}{2P\phi}\right)^2\right]^{1/2}.$$

The quantity of total investment, $I$, can be determined via $I = \delta K$. The capital adjustment costs, and the price for investment, $PI$, then can be easily obtained.

In a dynamic general equilibrium model, the analyst is typically interested in the adjustments generated in the finite time periods in response to parametric changes of selected exogenous variables. In addition, the model is run by using the GAMS. Hence, imposition of a terminal condition becomes pertinent for a discrete time dynamic model when there are out-of-steady-state transitional paths for the endogenous variables. Since the so-called terminal conditions are, in fact, conditions for the steady state, an ideal terminal period should be chosen when a steady state is asymptotically approached.

In administering the dynamic experiments, two criteria are generally used to select the "convergence" of a steady state: the first is the time horizon when 99.99 percent of the transitional life of the main variables is realized; and the second is the time period when all endogenous variables cease to change by less than 0.000001 percent. However, for a large size global model, the computation ability of the software or computer used may prevent application of these two criteria. Implementing the time-aggregation techniques á là Mercenier and Michel (1994) reduces the required aggregate number of time periods and, hence, reduces the size of the numerical model. This method is applied in our simulation experiments.

Figure 1 -- Structure of the Model